# The New Millennium: Paperless Navigation for the U.S. Navy

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## BIOGRAPHY

Captain Paul Novak was raised in Connecticut, and in 1973 he received a B.S. in Biology from Stonehill College, North Easton, MA. He is a graduate of the Aviation Officer Candidate School, and was designated a Naval Aviator in 1975.

He has served as a Helicopter Anti-Submarine Squadron pilot for the SH-3 "SEA KING" helicopter and deployed aboard the aircraft carriers USS KITTY HAWK, and USS RANGER. He attended the Naval Postgraduate School in Monterey, CA, and was awarded a Masters of Science in Computer Systems Management in 1980. In 1984 he was designated an Aerospace Engineering Duty Officer, and reported to the IBM Federal System Division facility in Owego, New York, as SH-60B "SEA HAWK" Flight Acceptance Test Pilot, and Naval Air Systems Command Program Managers Representative for the Light Airborne Multi-Purpose System (LAMPS) MK III Program. In 1987 he reported to the Naval Air Systems Command Headquarters in Washington, DC, as the Avionics Systems Project Officer for the LAMPS MK IIL/SH-60B, and the VH-3D and VH-60N Presidential Helicopters. In 1990 he completed the Program Managers course at the Defense Systems Management College, FT Belvoir, VA, and was reassigned to the Naval Air Development Center, Warminster, PA. as Director of the Vertical Flight Division. At NADC he led a team of 50 scientists and engineers delivering hardware and software products to the fleet and to various Naval Air Systems Command Program Offices. In 1993 Captain Novak reported to the Space and Naval Warfare Systems Command, Washington, DC, where he directed the integration of Global Positioning System into 86 different kinds Of U.S. Navy, Marine Corps, and Coast Guard aircraft. On 14 June 1996 he assumed command as Program Manager, Navigation Systems at the Space and Naval Warfare Systems Command where he is responsible for the integration of GPS into all U. S. Navy, Marine Corps and Coast Guard aircraft, and the Navy ships and submarines.
His personal decorations include the Meritorious Service Medal (two awards), the Navy Commendation Medal (two awards), and the Navy Achievement
Medal. He is a designated Acquisition Professional.

Patrick Baccei graduated from the University of California at Davis in 1973 with a Bachelor of Science Degree in Electrical Engineering. His Navy career assignments included multiple tours in surface ships, submarines and submersibles. He was Officer in Charge of the Deep Submergence Rescue Vehicle MYSTIC (DSRV 1), and commanded the submarine rescue and diving vessel USS SUNBIRD (ASR 15) and the Navy's Deep Submergence Rescue Unit. His last Navy assignment was as Assistant Program Manager for Electronic Charting and Navigation to the Navigation Systems Program Office (PMW 187) at the Space and Naval Warfare Systems Command (SPAWAR). While at SPAWAR, he was responsible for the charting interests of the Navigation Sensor System Interface Program and he represented the Navy to the Mapping, Charting, Geodesy and Imagery component of the Defense Information Infrastructure Common Operating Environment. He is currently employed by Lockheed Martin Marine Systems.

## ABSTRACT

The evolution of navigation and the advances in companion technology in the last millennium have set the stage for a new U.S. Navy navigation paradigm: paperless navigation. To the naval mariner and warfighter, paperless navigation will mean improved safety of navigation, greatly enhanced ship control, and a common, distributed navigation picture.

Hundreds of years ago, mariners kept track of the latitudes they sailed on, crudely and inefficiently adjusting their courses and approaches as they made their

way to known latitude destinations. Eventually, time and longitude were added and the mariner could then reasonably deduce his true position within some number of miles. Mariners could then chart, with similar accuracy, the landmasses and features they encountered. This basic navigation process has been slowly honed and refined over time. During the final decades of the last century, quantum leap navigation advances were made. Namely, the availability of: continuous position fixing; paper charts in digital electronic media; the maturity and reliability of fast, compact, user-friendly computers; and finally, the capability and connectivity of ship-to-shore communications and onboard networks.

All the advances of the last thousand years aside, U.S. Navy navigators are still required to use traditional paper-based methods to execute the routine tasks of navigation such as: plan voyages, monitor progress along a track, plot observed navigation aids, analyze and explore alternate trial tracklines. These methods have proven laborious, time consuming, error prone and of constrained value to the overall process and product of navigation.

It can be no surprise that the Navy is poised for the next step, a dramatic change --- navigation of a ship with neither the need of a paper chart nor many of the traditional procedures required by the use of a paper medium. Paperless navigation can have many meanings, but for the purposes of this paper it is: computer based and displayed navigation, using charts rendered from electronic media. Further, it implies a system that: accepts and plots position information; displays it and other pertinent navigation items for operator analysis and decision; conducts and displays limited analysis actions of its own; provides status, indications and alarms; and accepts operator inputs and actions that contribute to or change the navigation picture. Paperless navigation will go a long way towards solving the problems and issues that navigators have struggled with through the ages. In concert, the stage is also set for a robust marriage to ship control systems that have similarly evolved and for a common distributed navigation picture.

SPAWAR PMW 187 fields a Program of Record system, the Navigation Sensor System Interface (NAVSSI) that has leveraged navigation and technology advances to address the problems and issues mentioned above. This system will be described in more detail in the next section.

U.S. Navy navigation has come a long way in both its capabilities and the demands placed on those capabilities. The next step involves a quantum jump ---a paradigm shift. This paper will set the stage for the shift, beginning with a primer of recent past and present developments. It will then take the reader through the transition and offer a glimpse of what's beyond. Finally, it will highlight the challenges to be met and overcome in the way ahead.

## THE LAST MILLENNIUM: FROM PAST TO PRESENT

A thousand years of mariners evolving the requirements, demands and desires placed upon shipboard navigation and technology spurred a corresponding millennium of improvement to the underlying navigation sensors, charts (products, accuracy, media), display capability and navigation procedures. This evolution, as depicted in Figure 1, has been heavily biased by relatively recent advances and has positioned the U.S. Navy to transition to paperless navigation.

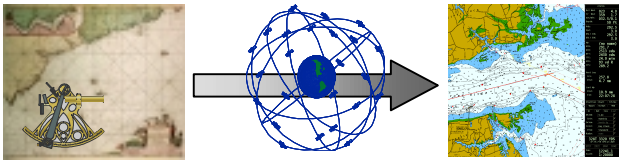

Figure 1. Navigation from the past to the present

Today's naval navigator faces a number of challenges to improve the results of his craft. At the forefront is a desire to reduce the number of groundings and collisions, placing emphasis on the personnel error factor. Other items on the list are: reduce information and analysis latency associated with traditional techniques; achieve constant position plotting, fixing and analysis; make the navigation picture available for navigation, command and control, tactical/strategic situational awareness; and finally, bring all the useful data (or at least make it available) to one screen. As the issues are pondered, the navigator is restricted by what can be done to improve matters based upon the limitations of paper-based navigation. Namely, voyage monitoring is plot intensive and results in discrete (as opposed to continuous) analysis of aged position data. Voyage, trial voyage, and trial maneuver planning is laborious and time consuming. Paper-based methods are historically prone to human error. The constraints of paper make data, overlay, picture sharing difficult, error prone and, at best, a manual process. Finally, not all of the source data a navigator uses for analyses can be readily or properly displayed on a paper chart.

Recent/near recent technology advances and improvements to the underlying navigation sensors, charts (accuracy, product and media) display capability and navigation procedures have opened the door for the navigator to be freed from reliance on paper-based methods. Some of the areas where related or supporting technology has made significant strides are:

- Navigation Satellites. Satellite positioning systems have gone from the original Transit system to a

neophyte, discretely capable Global Positioning System (GPS), to a 24-hour, world wide all weather GPS. Continuous and accurate position fixing is a reality.

- Computer systems. Computers have matured into compact, high speed, large memory capacity, robust and user-friendly stand-alone or network-compatible systems. Employment of these systems in a network architecture readily allows for the distribution of functionality and data. Present day computers are capable of handling the calculation and display requirements of paperless navigation.
- Mapping charting and geodesy (MC&G) data. Data accuracy has been boosted through improved and more accurate survey techniques. The Navy has adopted a standardized datum for navigation reference purposes ---WGS 84. Most important, the data is being made available on electronic media in various computer formats. The format adopted for Navy purposes is the National Imagery and Mapping Agency's (NIMA) Vector Product Format (VPF). The cornerstone VPF product that will be used for U.S. Navy vessel navigation is the Digital Nautical Chart™ (DNC).
- Supporting navigation technology. Sensor data collection, processing and validation have matured as well as the ability to distribute the processed information to a wide variety of user systems. NAVSSI bundles all these functions into one system.
- Inertial navigation systems have been refined and, in concert with GPS, the two systems enjoy significantly beneficial cross aiding. NAVSSI is connected to inertial systems on warships for this very reason.
- Radio communications: new communication systems and increased bandwidth (data transmission size/rates) to and from ships is making it possible to electronically distribute navigation data/media wherever and whenever it's needed. SPAWAR is fielding high bandwidth systems that will make the most efficient use of the transmission spectrum.

Systems exist or are on the drawing board to use the advances in technology to meet many or all of the challenges for navigation improvement. SPAWAR PMW 187's NAVSSI, has been on track since inception to make full use of today's technology. NAVSSI is the Navy's shipboard system that handles the collection, processing and distribution of navigation data. It is also on track to field a certified paperless, electronic chart display and information system – Navy (ECDIS-N). ECDIS-N is the cornerstone of U.S. Navy paperless navigation and will be discussed in more detail below. NAVSSI receives sensor inputs from such systems as GPS (actually housed in NAVSSI), inertial reference, depth sounders, speed logs, gyrocompasses, and radar (for ECDIS-N). After processing the input data, it distributes it to weapons systems and other command, control, computers, communications and intelligence (C4I) systems. NAVSSI's ECDIS-N component leverages off work being done by the Coast Guard namely, incorporation of the Coast Guard's Command Display and Control - Replacement (COMDAC(r)) system. In a mutual agreement saving millions of dollars, the Naval Sea Systems Command's (NAVSEA's) VIRGINIA class New Attack Submarine (NSSN) will also employ COMDAC(r) as its electronic navigation core capability.

Fundamental to NAVSSI is its system architecture concept of interoperability and commonality. Namely, its use of and reliance upon the Defense Information Infrastructure Common Operating Environment (DII COE) as implemented in the Navy's Global Command and Control System – Maritime (GCCS-M). Additionally and again based upon its architecture and functionality, it is the intended shipboard warehouse and distributor of NIMA digital products for many ships. NAVSSI is destined for installation on nearly 170 of the Navy's front line warships. With all this in place, NAVSSI is an ideal host for a charting system that will take the Navy paperless.

The U.S. Navy recognizes that the requirements of vessel navigation coupled with advances in technology make the timing right to begin the transition to paperless navigation now. It can see the benefits to be reaped in the areas of improved safety of navigation and possibilities for a robust marriage to ship control systems where appropriate. From this vision, the Navy has initiated an ECDIS-N Policy[1] containing planning guidance and system performance standards. Further, it directs transitioning the Fleet from paper-based navigation to navigation by means of digital charts with a goal of full implementation by 2007. Highlights of the Policy include:

- Use of Navy standard automated and continuous positioning systems. This translates to the use of DoD Joint Program Office (JPO)/SPAWAR PMW 187 approved GPS receivers for the GPS component.
- Requiring World Geodetic System –84 (WGS-84) as the standard datum.
- Use and proper rendering of Department of Defense standard data products. This means electronic chart data products produced by NIMA.
- Use of VPF as the standard digital data format. The required NIMA products exist or will be produced in this format.
- Attainment of system accreditation to at least DII COE compliance level 5.

Systems in the field today are evolving and migrating to Policy standards. They have been labeled "for situational awareness only" until the systems and the data products they use are formally certified. NAVSSI has been in constant step with the DII COE; others are working

toward that goal. Some ship platform types are eager to see ECDIS-N married to a ship control system. NIMA is preparing the charting products and the source update capability for use in the emerging systems. NIMA is also working towards the goal of a geospatial information warehouse, a concept where MC&G data will be accessible on one of the Defense Information System Agency's (DISA's) Internet protocol router networks. OPNAV and the Fleet Commanders in Chief (CINCs) are preparing for the certification of ship's navigation teams to use the certified ECDIS-N systems.

The stage has been set and it's time for the U.S. Navy to begin its transition to paperless navigation. In many cases, naval mariners have some form of "situational awareness" navigation hardware and software on their ships now and they're getting impatient to use it as a sole means of navigation. The critical elements of the Policy, candidate navigation systems and NIMA data products are taking shape. NAVSSI is poised to play a significant role in the "paperless" Navy.

**THE NEW MILLENNIUM: TRANSITION AND BEYOND**

Completing the transition will greatly enhance the safety of navigation and make available the best possible input to ship control. It will also help establish the common and distributed navigation picture as a key element of naval tactical and strategic warfare. This section will explore the underlying elements of the transition to paperless navigation and also look at how the Navy can leverage the transition to broader goals.

The elements of the transition emanate from the guidance and direction of the Policy letter. Along this vein, the Deputy Chief of Naval Operations for Resources, Warfare Requirements and Assessments (N8), further delegated to Director Surface Warfare (N86), will certify candidate ECDIS-N systems comply with the standards set forth in the Policy. With plans and procedures in development, the current intention is to certify an unspecified number of candidate systems and allow ship platform managers and, in some cases, fleet units maximum latitude in choosing the right system for their application. In addition to the highlighted requirements of the Policy outlined in the previous section, candidate systems are likely to undergo a battery of tests and inspections including a comprehensive Navigation Certification (NAVCERT), an Operational Evaluation (OPEVAL) and a companion shipboard operator certification implemented by the Fleet CINCs. In concert with the acceptance of a candidate system, the following system support must be in place: transition of traditional paper-based Fleet navigation and piloting procedures into the new paradigm, shipboard and formal operator training, initial and periodic operator evaluation, and system logistics. The path to getting a large number of Navy ships properly equipped and certified will be long and challenging. The goal should be, at minimum, to match the needs of a given ship to candidate system capabilities and also to fit system installations into shipbuilding and refit schedules ---the process of getting the right system to the right ship at the right time.

Figure 2. The Navy's most powerful warships will navigate

Roughly seven years down the road and at the end of this journey, the sea-going Navy of approximately 300 ships equipped with ECDIS-N systems will have transitioned to paperless navigation. Ships such as those in Figure 2 will be safer and more efficient in the execution of the navigation routine. Additionally, they will be ready to marry a sound ECDIS-N navigation input to ship control systems ---an input with attributes such as: multi-source/sensor fed; position solution and track recommendations continuously updated, analyzed and refined; and, navigator-in-the-loop processed output. In the context of the ship's bridge, ship control (helm and propulsion control) will normally bring with it the integration of other critical ship functions such as machinery monitoring/control and damage control.

There are benefits to be gained or leveraged from the transition that transcend ECDIS-N and ship control. Transitioned ships can: precisely conduct collision and grounding avoidance; pinpoint graphically where they are (where their weapon systems are) instantly; quickly voyage plan/trial maneuver themselves to a desired destination; lock the helm orders into their ship control systems; and, step back to a position of improved oversight. They can modify or enhance their individual navigation picture with the application of self-constructed or template overlays that can display such things as: force disposition, target information; Warship ECDIS (WECDIS) Additional Military Layers (AMLs) (such as the location of mines or mine avoidance routes; Movement Reports (MOVREPs); meteorological information; Optimum Track Ship Routing (OTSR) plans); logistics support concerns such as the need for fuel or provisioning; and, search and rescue areas with amplifying information. The list is not bounded. From the above, it logically follows that given the means to receive and distribute data and information, these same ships can import/export this or other navigation pictures and similar overlays to other information/control centers: aboard the same ship (via common local area network (LAN)); to or amongst Battle Group (BG)/ Amphibious

Readiness Group (ARG)/etc. elements, theater/global centers (via land line or radio-based communications). The resulting tailored, accurate, common and distributed navigation picture would provide the naval mariner and warfighter a significant piece of the tactical and strategic warfare picture.

NAVSSI is the one shipboard system that will be interoperable and integrated with other systems to the extent necessary for the successful fusing together of a common, distributed navigation picture. The system will handle all the necessary navigation functions and provide the data, displays and information for distribution to weapons systems, command and control systems, and ship control systems.

In summary, transitioned Navy ships will reap the benefits of:

- A robust system replacement to paper chart-based piloting and open ocean navigation.
- A fusion of sensor to chart and contact data for greatly enhanced collision and grounding avoidance.
- A solid navigation input to ship control systems.
- A position from which to leverage the distributed navigation picture to the added benefit of the naval mariner and warfighter.

Viewed as a force multiplier, the leveraged result will be:

- **A lethal force**: armed with the clearer and more complete picture of where they and their weapons are, what their situation is and where their lethality is aimed.
- **A focused force**: that is interoperable and command/control connected.
- **An extremely mobile and flexible force**: quicker to react, logistically supportable, less prone to voyage error/calamity (e.g., being at the wrong place at the wrong time, grounding and collision)

NAVSSI enjoys the enviable position wherein it is designed to help the Navy leverage the post-transition to broader goals. The future is indeed bright, but this paper cannot conclude without looking at the significant challenges that lay ahead as the new millennium begins.

## CHALLENGES TO THE WAY AHEAD

The products and processes to effectively launch and conduct the transition to paperless navigation are coming together and the impediments to progress are known. Considerable work remains to be done to properly address the challenges that range from Policy implementation and execution issues to what procedures and processes need to be transitioned from the traditional paper-based way of navigating the ship.

Specific areas where diligent effort is needed:

- Electronic Chart Display and Information System Policy implementation is not part of any Navy acquisition program or strategy.
- Candidate system certification: the process of putting this aspect of the policy into action is still under development. Plans and procedures must be approved in a timely fashion in order to prevent delays.
- Chart product maturity. NIMA is in the process of completing its 29 CD-ROM database of DNCs in VPF. Scheduled for completion in 2000 (in 1993 format), this digital database will require updating and a change to the to the 1996 format before NIMA will sanction it as suitable for primary navigation.
- VPF Data Update (VDU). In addition to the required database actions outlined above, the architecture and functional implementation of VDU is still under construction. The ability to update the source data information electronically (in addition to the separate ability to make manual corrections) is an ECDIS-N requirement.
- DII COE Compliancy. NAVSSI is the only ECDIS-N system built from the ground up to be compliant with the DII COE ---at any level. Other candidate systems must modify their systems in order to achieve the minimum of Level 5 accreditation.
- DII COE architecture and software development. The DII COE serves the broad needs of all the service branches in DoD and, as such, evolves in functionality at a limited pace. The DII COE-based mission applications like COMDAC in NAVSSI will have to adjust and adapt in order to synchronize their systems and software development schedules.
- Communications bandwidth and bandwidth management. Though SPAWAR is working to field higher bandwidth capable systems, there is significant work to be done to provide the Navy and its ships with the communications infrastructure support required for data intensive systems such as chart display and navigation systems.
- Data security. ECDIS-N requires the ability to access, manipulate and display potentially classified charting data. Though NAVSSI is prepared to operate with classified products, commercial systems will need to come to grips with security issues inherent to Navy and joint integrated systems.
- Proliferation of systems. It is likely that there will be at least three different ECDIS-N systems certified for use in Navy ships. Having more than one system makes training standardization difficult and inefficient. It also raises other logistics support issues such as the commonality of troubleshooting, repairs and repair parts.
- Working with shipbuilding and refit schedules. Equipment installation and checkout can only be done when ships are in port and normally only during an established timeframe dedicated to general

equipment maintenance, modification or installation. The smooth coordination of funding, development, production, installation and building/refit schedules will remain a challenge. It is also not uncommon to be unable to match available resources to tight schedules and thus lose the window of opportunity for installation. Careful planning and coordination for equipment installations is essential to optimizing efficiency and minimizing cost. Considering that the goal is the transition of 300 ships by 2007, the challenge is formidable.

- GPS signal vulnerability issues. The GPS signal is fragile and subject to interference. An ECDIS-N system must be capable of employing traditional navigation methods such as visual Lines of Position (LOP) fixing when electronic sensor input is lost/unavailable. ECDIS-N systems should not rely solely on the sustained availability of the GPS signal, but degrade gracefully when the GPS signal is lost.
- Paradigm shift for the Fleet. The Fleet has yet to transition existing paper-based navigational procedures into the new paperless paradigm. As candidate systems become certified and Fleet users begin to train and gain experience on them, the process will begin in earnest to wisely and judiciously incorporate or adapt traditional navigation methods into paperless functionality. In certain cases, the reapplication of traditional methods will be entirely unnecessary. The real challenge will be to support a paperless system with proven procedures that the trained naval mariner can use to sufficiently pilot and navigate in the leanest of sensor input scenarios.
- True interoperability and commonality. Interoperability and commonality make good sense and the Navy and the DoD have legislated them to a certain degree --- in reality they are somewhat difficult to implement. Add in meshing with our NATO/foreign interests like adopting WECDIS and the goal becomes harder to attain. With parochial interests figured in, true interoperability and commonality amongst ourselves and our allies will be an uphill challenge for years to come.
- Fast, cheap and good ---you cannot have all three. Getting to the objective of paperless navigation as fast as possible shouldn't be a goal. Limited resources dictate that the Navy seek the best affordable solution(s) and this takes time. Improvements to the safety of navigation aside, the Navy was wise to set the completion objective out to 2007.

It will take the next 1-2 years to completely address and resolve the above issues. The "long poles in the tent" are: getting certification plans and procedures agreed upon and implemented; chart product maturity and VDU; limited resources and coordinated scheduling; and, getting crews sufficiently trained and experienced in ECDIS-N system use and procedures.

## CONCLUSION

Shipboard navigation and companion technology have evolved and matured over the last 1000 years. In meeting the challenges that lie ahead, the U.S. Navy will launch the next millennium with the transition to paperless, all-electronic navigation and a distributed navigation picture. The Naval mariner and warfighter will then have what's needed at their fingertips to steam safely and efficiently; able to quickly evaluate, react and bring lethality to bare when and where needed or directed. Though this endstate is very appealing, we must be patient and focus the demands for our attention and limited resources where they can best be applied if we are to get there. NAVSSI is one system that stands ready to accept the challenges that lie ahead in the pursuit of paperless naval vessel navigation.

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